Testing the Diagnosis of Marine Atmospheric Boundary Layer Structure from Synthetic Aperture Radar

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LONG-TERM GOALS

My long-term goal is to continue to test and refine a similarity-based method for the extraction of marine atmospheric boundary layer (MABL) fluxes from synthetic aperture radar (SAR) wind-imagery of the sea surface. I have implemented this method on a limited number of SAR wind-images from off the east coast of the United States using bulk-derived statistics from coincident buoy data as ground-truth. Agreement is encouraging. The rate of acquisition of SAR wind-imagery available to me is scheduled to increase. Imagery will be available over the Gulf of Alaska as well as off the east coast of the United States, in conjunction with the National Oceanic and Atmospheric Administration (NOAA)-sponsored Storm Watch program. Therefore, the potential for robust testing of the method will exist. Questions I wish to address include the influence of the surface wave state, the synoptic and mesoscale meteorological environment, pixel size, and the averaging window size of the SAR wind-imagery on the performance of the method.

OBJECTIVES

Young et al. (2000) presents a method based on Monin-Obukhov and mixed-layer similarity theory that uses the variance of SAR-derived wind imagery in the presence of statically unstable MABLs to generate diabatic wind imagery and, in the process, calculate several MABL statistics including the Obukhov length (L). A byproduct of this method is the surface buoyancy flux (B).

Young et al. (2000)'s data set is limited to low wind speed and small air-sea temperature difference environments. My objective is to extend the work of Young et al. (2000) to environments with larger wind speeds and air-sea temperature differences. No *in situ* turbulence data are concurrent with the SAR data set used my research. However, several NOAA National Data Buoy Center (NDBC) buoys are present in the imaged areas. I therefore compare SAR-derived MABL statistics to those produced by the Tropical Ocean-Global Atmosphere Coupled Ocean-Atmosphere Response Experiment (COARE) 2.5 Bulk Flux method (Fairall et al. 1996) which uses the buoy data as input. In this light, my research should be viewed as a test of a method that, if successful, can compete with COARE 2.5-buoy estimates of MABL statistics.

APPROACH

The key variable used as input for the SAR method is the variance of the wind imagery resulting from MABL convection. This variance (σ_u^2), combined with the SAR-derived MABL depth estimate (z_i) (via the technique presented in Sikora et al. (1997)) and the SAR-derived friction velocity (u_*) (via the

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wind imagery, the log wind law, and the Charnock relation), is used to calculate an L in the convective limit;

$$L = -z_i / (((\sigma_u / u_*)^2 - 4) / 0.6)^{3/2} . \tag{1}$$

L is in turn used to calculate a diabatic drag coefficient (c_d) via

$$c_d = (k / (\ln(z / z_o) - \Psi_m(z / L)))^2 . \tag{2}$$

In Eq. 2, k is von Karman's constant (0.4), z is the instrument height, z_o is surface roughness length calculated following Smith (1988), and Ψ_m is the stratification function given by Paulson (1970). c_d is combined with u_* to produce a diabatic wind speed image. The family of equations are solved by iteration, with refined values of L resulting in refined values of the wind speed. Convergence is rapid. B is obtained by solving the formal definition of L for that quantity,

$$B = -\frac{u_*^3 T_v}{Lkg} , \tag{3}$$

where T_v is the surface virtual temperature in absolute units and g is the acceleration of gravity.

My research employs four RADARSAT overpasses from off the east coast of the United States. Most of this imagery can be viewed in Sikora et al. (2000). The three overpasses are from 14 January 1997, 17 January 1997, 06 March 1997 and 22 November 1997, all at about 2254 UT. I chose to use these overpasses in my research because they are concurrent with strong cold air outbreaks and because several NDBC buoys are present in each scene. All buoy averaging times for the data used in the COARE 2.5 method are 8 min and are calculated just prior to the top of an hour. Therefore, the buoy averages correspond almost identically in time with the SAR overpasses.

The SAR imagery are converted to wind imagery using the technique described in Thompson and Beal (2000). Caution must be taken during the transfer from normalized radar cross section (NRCS) to wind imagery. For one, the relationship between NRCS and wind speed is highly dependent on the near-surface wind direction. The near-surface wind direction over the ocean can be quite variable, especially at high resolution in convective environments. Moreover enhanced or decreased backscatter due to oceanographic, as well as speckle noise can contaminate the SAR wind estimate (Mourad et al. (2000). Thus, when converting SAR imagery to wind imagery, it is usually desirable to apply some spatial smoothing. This smoothing minimizes contaminating variance while still providing a resolution high enough to preserve MABL convective signatures. I adopt the recommendation found in Thompson and Beal (2000) and Mourad et al. (2000) of smoothing to a 300-m pixel size; however, additional research is needed to test the validity of the choice.

Using the 8-min average buoy wind speeds and invoking Taylor's hypothesis, portions of each resulting wind image are cropped in such a way that the spatial data from the resulting sub-scene can be compared to the temporal data of the buoy. These square sub-scenes range in size from 17.6 to 51.8 km^2 and are used as input for the SAR method.

WORK COMPLETED

Task 1. Select appropriate SAR wind-imagery from in-house collection at The Johns Hopkins University Applied Physics Laboratory (JHU/APL).
Who: Todd Sikora
Time: Summer 1998

Task 2. Cross reference SAR imagery with collocated buoy and remote sensing data.
Who: Todd Sikora and Midshipman 1/C John Bleidorn
Time: Summer and Fall 1998

Task 3. Use collocated buoy data to determine *L* and *B* at the time of each SAR overpass.
Who: Todd Sikora and Midshipman 1/C John Bleidorn
Time: Spring 1999

Task 4. Apply the SAR method to each SAR wind-image scene and generate plots of SAR-derived *L* and *B* versus COARE 2.5-derived *L* and *B* (see RESULTS section)
Who: Todd Sikora
Time: Spring and Summer 1999

RESULTS

Figure 1. shows the results from my research for all of the case studies when the MABL was weakly

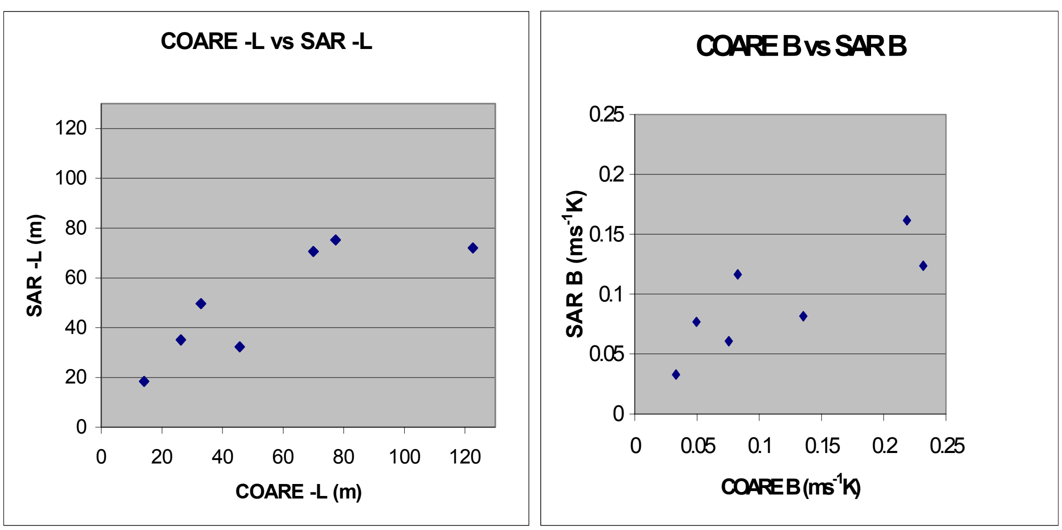

Figure 1. Comparisons of SAR- and COARE 2.5-derived L and B.

to moderately unstable (two of the cases studies were of near neutral MABLs). As can be seen, agreement between the two methods is encouraging. However, in general, the SAR method underestimates the results of the COARE 2.5 method, especially at the larger –*Ls* and *Bs* generated by the COARE 2.5 method. Given the relatively sparse amount of available data up to the time of this writing, it is difficult to assign specific causes for the deviations seen between the two methods. Future work will address questions designed to reveal the causes for the observed differences.

IMPACT/APPLICATIONS

The above-mentioned SAR-MABL similarity theory techniques have the potential to provide accurate MABL wind and flux measurements at a very high resolution. Verification of the usefulness of these techniques is important to those communities that would benefit from their implementation such as synoptic-scale and mesoscale operational numerical weather prediction.

TRANSITIONS

The research I'm conducting will be applied to data sets containing *in situ* turbulence data coincident with SAR imagery. At this time, one such data set is in hand and is described in Thompson and Beal (2000). This research has the potential to reveal errors in both the SAR and COARE 2.5 method associated with the break-down of Monin Obukhov similarity theory due to the presence of young seas and swell (Donelan et al. (1997).

RELATED PROJECTS

My research is being coordinated with that Donald R. Thompson of JHU/APL. His ONR-funded research is focused on scattering issues related to the extraction of wind speed from SAR imagery. Recall that the proposed research relies on this wind image extraction. Dr. Thompson has found cases where SAR-derived wind spectra differ significantly from corresponding *in situ* spectra. It is believed that some of the observed differences are due to the fact that fluctuations in the SAR imagery, especially at the shorter spatial scales, can be caused by complicated scattering and surface-wave hydrodynamic processes as well as by direct wind variation. These non-direct wind-related fluctuations in the SAR imagery are produced, for example, by pixel-to-pixel changes in the surface tilt or by changes in the spectral density of short surface waves due to hydrodynamic modulation which varies across the phase of the longer waves. Dr. Thompson is attempting to understand how to more accurately characterize and isolate these two different processes as well as to research other possible mechanisms for the observed differences.

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